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OPTIMUM METHODS FOR THE MEASUREMENT OF THE ABSORPTION COEFFICIENTS OF MATERIALS

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Summary

For the measurement of the absorption coefficients of materials in a reverberation room, the method currently used by the BBC differs from the ISO-Standard method, in the use of additional diffusion in the room and in the distribution of the sample. For the ISO-Standard method, adequate diffusion is achieved by using additional diffusing elements in the reverberation room, whereas the BBC method relies on the distribution of the sample.

In this Report, ISO-Standard absorption coefficient measurements are shown to be more appropriate to the design of heavily treated rooms. Absorption coefficient measurements made using the BBC method are more appropriate to the design of sparsely treated rooms.

To ensure that measurements at low frequencies in the old reverberation room at Research Department are as reliable as possible, the existing BBC method for the measurement of the absorption coefficients of subdivided samples will continue to be used; additional diffusing elements are not then required. If the sample cannot, or would not usually be subdivided, additional diffusing elements will be installed.

The ISO-Standard method for the measurement of the absorption coefficients of materials will be used in the new reverberation room. The use of the ISO-Standard method should reduce the influence of 'edge effects' on the measured absorption coefficients.

Index terms: *Sound; reverberation; rooms; absorbers*

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1. INTRODUCTION

For many years, it has been BBC practice to measure the absorption coefficients of materials using a different method to the ISO-Standard method for measurement of absorption coefficients in a reverberation room[1]. There have been very good reasons for using the BBC method which was developed as a result of a series of detailed studies[2].

A potential complication arises now that a new reverberation room (the receive room of the Research Department Transmission Suite[3]), which complies with the ISO-Standard requirements for reverberation rooms, has been built (details of the old and new reverberation rooms are given in the Appendix). If any external body to the BBC was allowed to use the new reverberation room for absorption coefficient measurements, the ISO-Standard measurement method would probably be adopted. Also, if the absorption coefficient of a material measured by the BBC in the new reverberation room was to be compared directly with the absorption coefficient of another material measured elsewhere using the ISO-Standard method, then the BBC would also have to use the ISO-Standard method for compatibility reasons.

The two differences between the ISO-Standard method and the current BBC method are in the use of additional diffusion in the room and in the distribution of the sample. A diffuse sound field in the reverberation room is necessary for absorption coefficient measurements to be valid[4]. The ISO-Standard recommends the use of unabsorbent diffusing elements to achieve adequate diffusion, whereas the BBC method relies on the distribution of the sample. The ISO-Standard recommends that the sample should be laid out on the floor of the reverberation room as one patch of rectangular shape with a ratio of width to length of between 0.7 and 1.0. In the BBC method, materials that are usually mounted as one patch on one surface of a room (for example carpets or ceiling tiles), would be measured as one patch on the floor of the reverberation room. But with materials that are usually distributed over several room surfaces, the material would be measured as four patches of approximately equal area; these patches would be mounted on three walls and the floor of the reverberation room.

There are good arguments in favour of each method. Previously, the following arguments have been advanced in favour of the BBC method:

1. Eyring's formula[5] for the calculation of absorption coefficients, from measurements of empty and treated room reverberation times, is only valid when the sound field in the room is diffuse. The sound field in a reverberation room can usually be made sufficiently diffuse to allow reliable measurements, either by the use of a subdivided sample[2] or by the installation of a number of unabsorbent diffusing elements. Provided that the sample has been subdivided as in the BBC method, then it would not usually be necessary to install the additional diffusing elements in the reverberation room that are required in the ISO-Standard method.

2. For most of the measurements made in the old reverberation room, the BBC method was used. For compatibility with previous measurements, there is a good case for retaining the same measurement technique.

3. The effective absorption coefficients of absorbers in large, sparsely treated rooms have been shown[6] to agree more closely with reverberation room measurements on subdivided samples rather than undivided samples. This is because the subdivided sample, in the reverberation room, more closely represents the way in which the absorber is distributed in the large, sparsely treated room, which is important, as the small patches of absorber will interact with each other.

Arguments in favour of adopting the ISO-Standard method are:

1. In the BBC method, for the measurement of the absorption coefficients of materials that are usually mounted as one patch on one room surface, the sample would also be mounted as one patch in the reverberation room. There would be inadequate diffusion in the reverberation room, as diffusers usually would not be installed for this type of BBC measurement.

   It has been suggested in the past that a lack of diffusion in the reverberation room is not important, as there is often insufficient diffusion

in studios. However, as stated above, Eyring's formula for the calculation of absorption coefficients is only valid when there is a diffuse sound field in the room. It does not apply in non-diffuse fields. Although it is possible to evaluate an 'effective absorption coefficient' of a material in a non-diffuse field, it would be incorrect to assume that a summation of 'effective absorption areas' in a non-diffuse room would give a reliable estimate of the resulting reverberation time in that room. This is because, in non-diffuse sound fields, absorbers affect the 'effective absorption coefficients' of each other, and they also affect the state of diffusion in the room.

Provided that a sufficient number of diffusing elements have been suspended in the reverberation room, when adopting the ISO-Standard method, the sound fields will be diffuse for both the empty and the treated room measurements. The BBC method relies on the distribution of the sample to achieve adquate diffusion, but the sound field may not be sufficiently diffuse in the empty reverberation room.

2. The ISO-Standard measurement method is employed for the majority of absorption coefficient measurements made in reverberation rooms outside the BBC. The ISO-Standard method was originally developed with the intention of obtaining the closest possible agreement between measurements made in different reverberation rooms; at the same time, it was intended to maintain reasonably close agreement between the absorption coefficients of materials measured in reverberation rooms and the effective absorption coefficients of the materials in real rooms. Measurements made in the new reverberation room, using the ISO-Standard method, should be directly comparable with measurements made in other reverberation rooms, using the same method.

   If a change in measurement technique was considered necessary, it would be sensible to implement the change before many measurements have been made in the new reverberation room. In any case, absorption coefficient measurements made in the old and new reverberation rooms show some disagreement, particularly at lower frequencies (because the modal density at low frequencies in the old reverberation room is insufficient to give accurate results). Therefore, compatibility with measurements made in the old reverberation room is not strictly attainable, which tends to negate the argument for retaining the BBC method in the new reverberation room on grounds of compatibility with previous BBC measurements.

3. The ISO-Standard measurement method reduces the variability in absorption coefficient measurements caused by 'edge effects'[7-12]. Sound is diffracted because of the presence of the absorber in the room. At low frequencies, diffraction occurs by virtue of the size of the absorber (this effect is analogous to diffraction of light through a rectangular aperture). At higher frequencies, diffraction occurs at the edges of the material (this effect is analogous to diffraction of light at the edge of a semi-infinite obstacle). Diffraction increases the effective area of the sample. Although high frequency diffraction occurs at the edges of the material, the edges themselves do not absorb. Theoretical and practical studies have shown that the relationship between the absorption coefficient of a material and the ratio of the exposed edge length to surface area of an absorber, is linear for large samples. As the sample size is reduced, the linear relationship no longer applies when the physical dimensions of the sample approach the wavelength of the sound. Then the absorption coefficient gradually tends to a limiting value. Subdividing a sample increases the exposed edge length and this results in an increase in the measured absorption coefficient.

   For absorbers with an appreciable depth, the greater relative side area exposed on sub-dividing the sample increases the measured absorption coefficients. This effect is not usually considered to be an 'edge effect'. Ideally, the exposed edges of a sample should be shielded with a reflective material when the absorption coefficient of the material is being measured in a reverberation room. Calculations have shown that this effect was insignificant for all of the measurements included in this Report; therefore, it was not corrected for in the calculations. The disadvantage of sub-dividing the sample (as in the BBC method) is that it is difficult to subdivide samples in a consistent way. Therefore, measurements on different types of absorber (or from different laboratories with different subdivision methods) will be inconsistent.

4. The effective absorption coefficients of absorbers in relatively highly treated rooms seem to agree more closely with ISO-Standard absorption coefficient measurements than

present BBC measurements (as explained later in this Report). For some time, there has been a trend towards more highly treated rooms within the BBC. Therefore, ISO-Standard measurements have become more appropriate than they were in the past for room design calculations.

Preliminary investigations have shown that the differences between the absorption coefficients which were measured using the BBC and the ISO-Standard methods, seem to be relatively small in comparison with the observed differences between the effective absorption coefficients of absorbers in various studio environments. Thus it would be difficult to say, conclusively, which is the more appropriate measurement method, as the reverberation times in a room, predicted from absorption coefficients measured using either method, would only differ by a small amount. The ISO-Standard method could be adopted, to ensure consistency with measurements made in other reverberation rooms, provided that it can be shown that the differences between measurements, made using the two methods, are small in all cases. This Report describes a more thorough investigation of the effects of the measurement method on the measured absorption coefficients.

It is not, in any way, intended to diminish the importance, nor to discount the validity of the reasons for previously adopting the BBC method, nor indeed the importance and the extent of the work which went into the derivation of the ISO-Standard. The purpose of the work described in this Report was to determine whether the recent changes that have occurred within the BBC are sufficient to warrant the adoption of the ISO-Standard method for future work. These changes include: the availability of a new ISO-Standard reverberation room; the widespread adoption of the ISO-Standard by other laboratories; and the gradual change to more heavily treated rooms in the BBC.

2. STUDIO AND REVERBERATION ROOM MEASUREMENTS

The purpose of reverberation room measurements of the absorption coefficients of materials, is to provide information that will allow a prediction of the resultant reverberation times in a room when various quantities of different absorbers are introduced. Therefore, it is a major requirement of any method adopted for reverberation room measurements, that the method should give results which are reasonable approximations to the effective absorption coefficient of the material measured in *any* room. A secondary requirement of the method for reverberation room measurements, is that it should give sufficiently repeatable results.

In cases where the reverberation times in treated rooms are lower than those predicted from absorption coefficient measurements made in reverberation rooms (that is, the apparent absorption coefficients are higher than those measured in the reverberation room), the cause is usually excess anomalous absorption that was not allowed for in the design. However, in very large, sparsely treated rooms, the effective absorption coefficients of materials have been measured[6] to be higher than those measured in reverberation rooms of typical size. Absorption coefficients have been shown to increase both with the room volume and with the ratio of the room surface area to the absorber area.

In cases where the reverberation times in treated rooms are higher than those predicted from absorption coefficient measurements made in reverberation rooms (that is, where the apparent absorption coefficients are smaller than those measured in the reverberation room), the cause is usually inadequate diffusion in the treated room. When the sound field in a room is non-diffuse, the angles over which sound is incident upon absorbers are restricted. Thus, the absorption efficiencies of the absorbers are reduced. Another possible cause of a reduction in the effective absorption coefficients of absorbers occurs when a room is very heavily treated. In this case, virtually none of the absorber edges will be exposed. Therefore the effective absorption coefficients of the absorbers will be less than the coefficients as measured in the reverberation room.

There is little information available concerning the effective absorption coefficients of single samples of absorbers in studio environments within the BBC. When constructing or refurbishing a studio, it is common BBC practice to measure the reverberation times before and after the acoustic treatment has been installed. However, it is not possible to separate accurately the contribution of any particular absorber to the overall absorption without making further measurements. To calculate the effective absorption coefficient of any particular absorber, the reverberation times would have to be measured both in the fully treated room and in the room without that particular absorber present.

2.1 Measurements in the experimental sound control room

To gain information on how absorbers behave in studio environments, the effective absorption coefficient of BBC type A3 (mid and high frequency) modular absorbers was measured in the experimental

sound control room at Research Department (other unrelated experiments on the interaction of absorbers in this sound control room are described in Ref. 13). Other acoustic treatment in the room consisted of carpet tiles on a raised timber floor, ceiling tiles in a suspended frame, and BBC type A2 (low frequency) modular absorbers. The walls of the fully treated room were almost completely covered with the A2 and A3 modular absorbers. To calculate the effective absorption coefficient of the A3 modular absorbers, 56 out of the 81 present were removed (there were 31 A2 absorbers in the room). The reverberation time measurement, with 56 of the A3 absorbers removed, corresponded to the 'empty' room. All the A2 and A3 absorbers were in place for the 'treated' room reverberation time measurement. The sample area removed was quite large (20 m^2), in order to reduce experimental errors (a measurement with only 28 of the A3 absorbers removed gave a similar shaped absorption coefficient curve, although measurements below 400 Hz were more erratic).

Fig. 1 shows the effective absorption coefficient of the A3 absorbers in the experimental sound control room, compared with absorption coefficient measurements made in the new reverberation room, using both the BBC and ISO-Standard methods. Between 160 Hz and 1.6 kHz, the effective absorption coefficient is generally lower than the measurements made in the reverberation room.

The differences between the two reverberation room measurements are generally much less than the differences between the effective absorption coefficients measured in the sound control room and either reverberation room measurement. From consideration of these results, it would be very difficult to select the more appropriate reverberation room measurement method.

Fig. 2 emphasises the effects, on the predicted reverberation times in a room, of the differences between the absorption coefficient measurements made using the BBC and the ISO-Standard reverberation room methods. The room design is for the experimental sound control room. One curve shows the predicted reverberation times using absorption coefficients measured by the BBC method. Another curve corresponds to calculations based on ISO-Standard measurements. The differences between the two curves are smaller than the differences that are observed between either curve and the reverberation time curve for the practical realisation of the room. Again, it is not possible to be confident about which reverberation room method gives more appropriate calculated reverberation times.

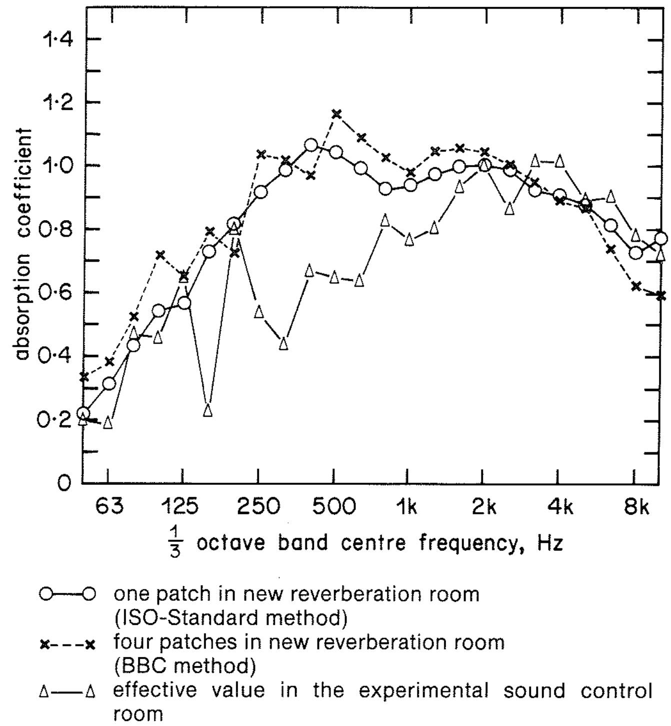


Fig. 1 - A comparison between the absorption coefficients of A3 modular absorbers measured in the new reverberation room and the effective absorption coefficients of A3 modular absorbers measured in the experimental sound control room.

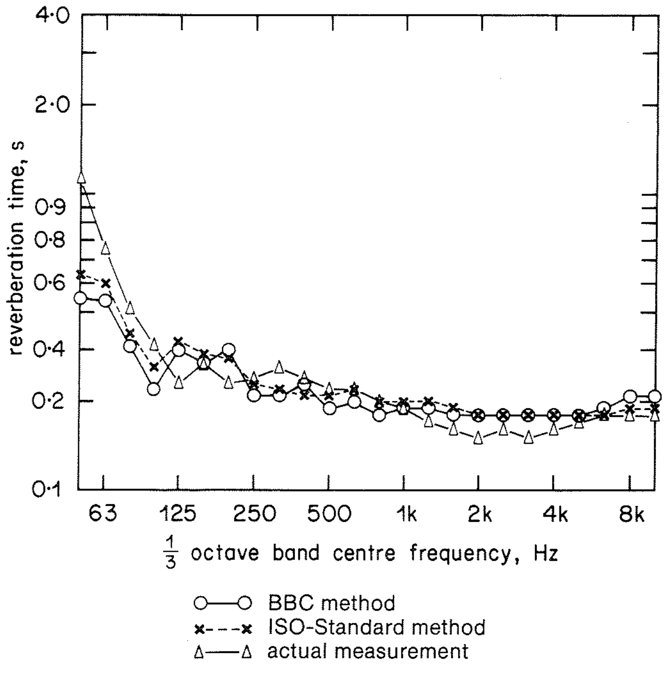


Fig. 2 - The effects of the method used to measure absorption coefficients in the reverberation room on the predicted reverberation times in a typical sound control room.

2.2 Measurements in the old reverberation room

To investigate further the ways in which absorbers interact in a room, the absorption

coefficients of A2 and A3 modular absorbers were measured in various configurations in the old reverberation room, with six diffusers installed. The reverberation room has a size comparable with a typical sound control room; the experiments were intended to simulate the ways in which absorbers interact in a typical studio with adequate diffusion. The sample areas of the A2 and A3 absorbers were both 7.2 m^2 in all measurements. Absorption coefficients were measured for the following:

1. (a) A2s in one patch on the floor (ISO-Standard method).
   (b) A3s in one patch on the floor (ISO-Standard method).
   (c) A2s and A3s as single patches laid alongside each other on the floor.

2. (a) A2s in a chequerboard arrangement on the floor.
   (b) A3s in a chequerboard arrangement on the floor.
   (c) A2s and A3s as interleaved chequerboard arrangements on the floor.

3. (a) A2s in four separate patches on three walls and the floor (BBC method).
   (b) A3s in four separate patches on three walls and the floor (BBC method).

4. (a) A2s in a chequerboard arrangement on three walls and the floor.
   (b) A3s in a chequerboard arrangement on three walls and the floor.
   (c) A2s and A3s as interleaved chequerboard arrangements on three walls and the floor.

2.2.1 Adjacent absorbers in heavily treated rooms

Measurement 1(c) described above was intended to simulate large patches of independently mounted absorbers. The effective absorption coefficient of the combined A2 and A3 absorbers is shown in Fig. 3, together with the arithmetic mean of the two individual measurements (1(a) and 1(b)). The two curves show reasonably close agreement except at 100 Hz, 125 Hz and 500 Hz. The differences at 100 Hz and 125 Hz probably occurred because of the low modal density in the reverberation room, at low frequencies, when measuring the absorption coefficient of the A2 absorbers alone. When the A3 absorbers were added, they would have altered the sound field in the room, which might have affected the interaction of the A2 absorbers with the room modes, at low frequencies. The results of measurement 1(c) did not agree closely with the means of the results for any of the other individual measurements.

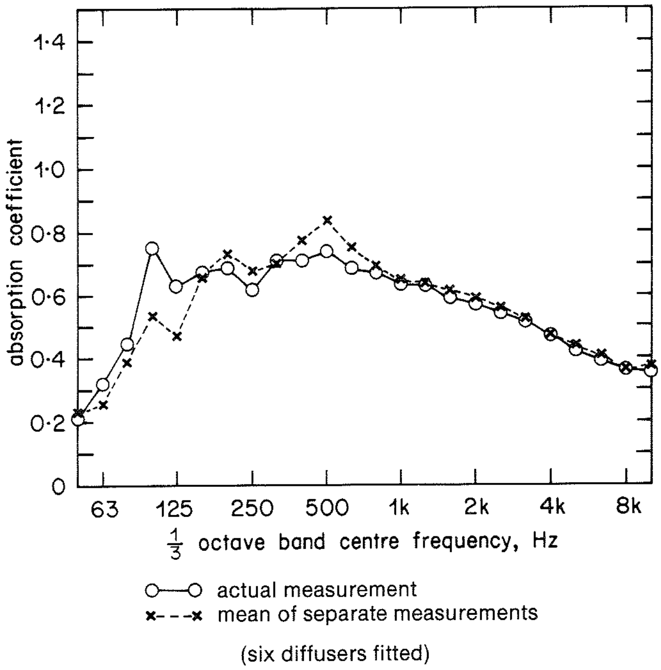
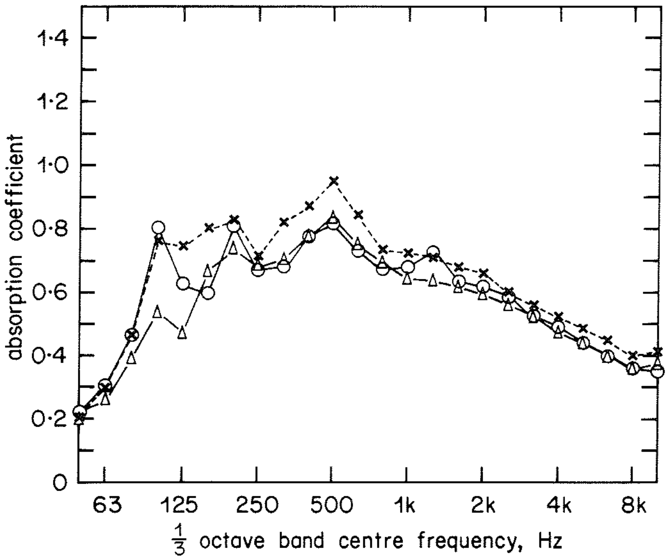


Fig. 3 - The absorption coefficients of separate patches of A2 and A3 modular absorbers on the floor of the old reverberation room.

These results indicate that the effective absorption of a number of large patches of independently mounted absorbers on one room surface can be best estimated from individual measurements of the absorption coefficients of the absorbers laid out as single patches. Thus, ISO-Standard measurements are more appropriate than BBC measurements, when the absorbers are to be used as large independent patches. The same may be true when the absorber is mounted as large, independent patches on more than one room surface, for the reasons given later in Section 4.1 (although insufficient absorbers were available to verify this hypothesis).

2.2.2 Interleaved absorbers in heavily treated rooms

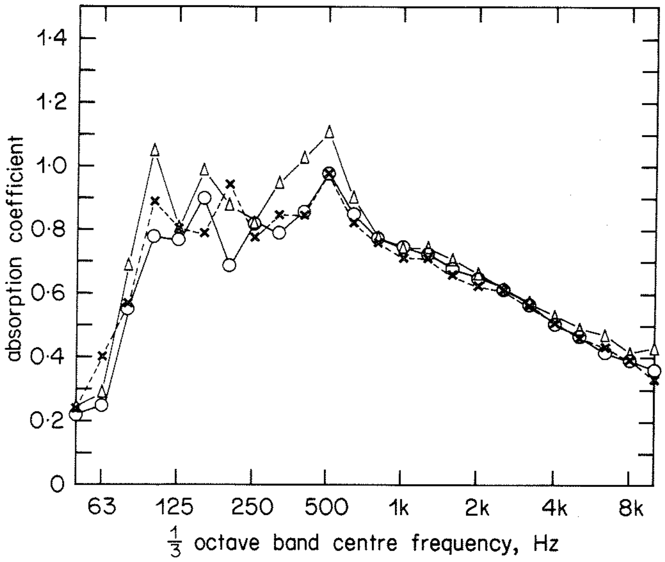
Measurement 2(c) was intended to simulate large patches of interleaved absorbers in a room. Fig. 4 shows the effective absorption coefficient of the combined A2 and A3 absorbers. Also shown, are the arithmetic means of the two individual measurements with the samples laid out in a chequerboard pattern (2(a) and 2(b)) or as single patches (1(a) and 1(b)) on the floor. At most frequencies, the measurement curve shows closest agreement to the mean of the separate single patch measurements (also, the effective absorption coefficient did not agree well with the mean of the individual measurements made using the BBC method, although for clarity this curve is not included on the graph). The absorption coefficients at 100 Hz and 125 Hz, for the mean of the single patch



o—o actual chequer measurement
x---x mean of separate chequer measurements on the floor
Δ—Δ mean of separate single patch measurements on the floor

(six diffusers fitted)

Fig. 4 - The absorption coefficients of interleaved A2 and A3 modular absorbers on the floor of the old reverberation room.



o—o actual chequer measurement
x---x mean of separate four patch measurements — not chequer
Δ—Δ mean of separate four patch measurements — chequer

(six diffusers fitted)

Fig. 5 - The absorption coefficients of interleaved A2 and A3 modular absorbers on three walls and the floor of the old reverberation room.

measurements, are too low for the reasons given in the previous section.

The effective absorption of a number of large patches of interleaved absorbers on one room surface, seems to be best estimated from individual measurements of the absorption coefficients of the absorbers disposed as single patches. ISO-Standard measurements are more appropriate than BBC measurements when the absorbers are to be used as large, interleaved patches. The mean of the separate chequer patch measurements is generally too high, as an estimate of the effective absorption coefficient of the combined absorbers, because most of the edges of the absorbers are exposed. When the absorbers are interleaved, they shield the edges of each other; this edge shielding occurs despite the fact that the A2 and A3 absorbers absorb over different frequency ranges. When the absorber is mounted as large, interleaved patches on more than one room surface, the same conclusion may apply (insufficient absorbers were available to verify this hypothesis).

2.2.3 Interleaved absorbers in sparsely treated rooms

The purpose of measurement 4(c) was to simulate small patches of interleaved absorbers on different surfaces of a room. The effective absorption coefficient of the combined A2 and A3 absorbers is shown in Fig. 5. Also shown, are the arithmetic means of the two individual measurements, with the samples mounted on three walls and the floor, either as four single patches (3(a) and 3(b)) or in four chequerboard patterns (4(a) and 4(b)). The measured effective absorption coefficient curve shows closest agreement to the mean of the separate single patch measurements on four walls.

The effective absorption of a number of small patches of interleaved absorbers on four room surfaces is, therefore, best calculated from individual measurements of the absorption coefficients of the absorbers disposed as single patches on four room surfaces. Measurements using the BBC method, are more appropriate than ISO-Standard measurements for predicting the effective absorption coefficients of combined absorbers in this case. These results again show that when the absorbers are interleaved, they shield the edges of each other.

2.2.4 Comments

The results of these experiments indicate that it would be better to use absorption coefficient measurements made using the ISO-Standard method when designing heavily treated rooms. Absorption coefficient measurements made using the BBC method are more appropriate to the design of sparsely treated rooms. But it must be stressed that the differences between absorption coefficients measured using the two methods are generally not large.

3. SAMPLE DISTRIBUTION AND DIFFUSION EFFECTS

3.1 Low frequency diffusion measurements

One of the stated reasons for distributing the sample, when making absorption coefficient measurements, is to increase the state of diffusion in the reverberation room. If the sample is measured as one patch, adequate diffusion can be achieved by the installation of additional diffusing elements in the room. Acrylic sheets (size $1800 \times 1200 \times 2$ mm), suspended randomly in the new reverberation room, have been used for this purpose[3], although they have only been proved to be effective as diffusers above 160 Hz. Measured absorption coefficients should change (usually increase) as the number of diffusing elements in the room is increased, until sufficient elements have been added, at which point, no further change in absorption will be observed on adding more elements.

To investigate whether the acrylic sheets were effective as diffusers below 160 Hz, the absorption coefficient of a single patch of type D2 modular absorbers was measured in the new reverberation room, with different numbers of acrylic diffusing sheets randomly suspended in the room. The results are shown in Fig. 6. The differences between the curves above 5 kHz probably result from some inaccuracy in the estimation of the air absorption in the room. It is difficult to detect any trend in the differences between the curves below 800 Hz, although they show reasonable agreement at all frequencies except 63 Hz. The effects of the presence of different numbers of diffusers on the measured low frequency absorption coefficients, are much less marked than the effects that the diffusers had had on measured mid and high frequency absorption coefficients[3]. It is difficult to determine whether this is because the acrylic sheets are ineffective as diffusers at low frequencies, or because the state of diffusion in the new reverberation room, at low frequencies, is adequate without diffusers installed, or because the D2 modular absorbers provide adequate diffusion in themselves.

To investigate the effects of sample distribution on the state of diffusion in the new reverberation room at low frequencies, the absorption coefficient of four patches of D2 modular absorbers on four room surfaces was measured (with different numbers of diffusers present). The results are shown in Fig. 7. The absorption coefficients below 800 Hz are generally higher than those for the single patch measurements, although this is probably because of edge effects rather than increased diffusion. The diffusers only seem to have a pronounced effect on the absorption coefficient at 80 Hz.

The conclusion that can be drawn, from these two sets of measurements on D2 modular absorbers, and from earlier measurements, is that all subsequent measurements above 80 Hz should be reliable, provided that at least nine acrylic diffusers have been installed in the new reverberation room.

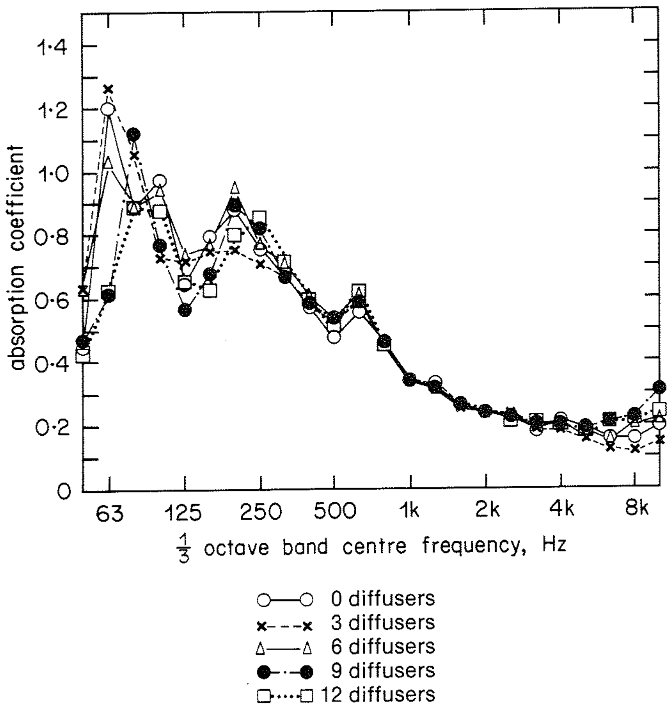


Fig. 6 - The effects of the number of diffusers installed in the new reverberation room on the measured absorption coefficients of a single patch of D2 modular absorbers.

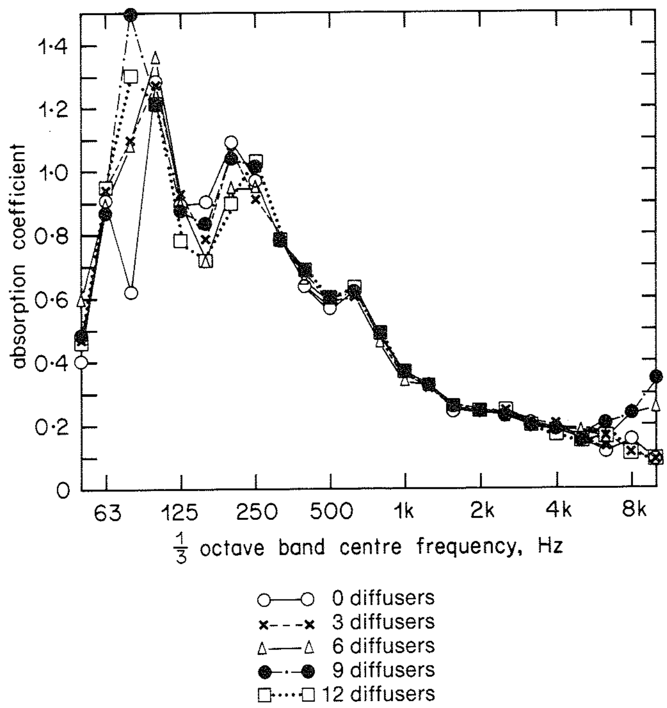


Fig. 7 - The effects of the number of diffusers installed in the new reverberation room on the measured absorption coefficients of four patches of D2 modular absorbers.

3.2 Mid and high frequency diffusion measurements

The present BBC method for the measurement of the absorption coefficients, of materials that are usually mounted as one patch on one room surface, has a drawback. Additional diffusing elements would not usually have been installed in the old reverberation room, when the absorption coefficients of such materials were being measured, so the sound field in the reverberation room would have been insufficiently diffuse. Because ceiling tile samples are measured as one patch, for both the ISO and the BBC measurement methods, the effects of additional diffusion in the reverberation room on the measured absorption coefficients were investigated.

The effects of installing acrylic diffusing sheets in the old reverberation room on the absorption coefficient of a sample of ceiling tiles are shown in Fig. 8, together with an ISO-Standard measurement (made in the new reverberation room). At lower frequencies, the absorption coefficient curve is smoothest for the measurement made in the new reverberation room (except for the dip at 125 Hz). Thus, the irregularity at low frequencies, observed in previous measurements, seems to have been a result of the small size of the old reverberation room — the small room size makes the modal density at low frequencies inadequate for reliable measurements.

The installation of six acrylic diffusing sheets in the old reverberation room increased the measured

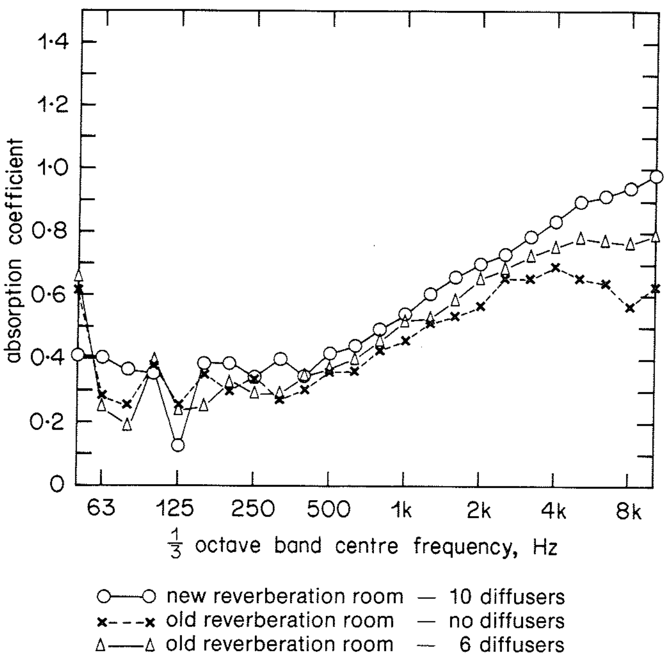


Fig. 8 - The effects of diffusers on the measured absorption coefficients of Armstrong Travertone Highspire ceiling tiles.

absorption coefficients of the ceiling tiles above 315 Hz. This shows that additional diffusing elements are required in the room when measuring an undivided sample of ceiling tiles. Absorbers are generally more effective at absorbing sound in diffuse fields rather than in non-diffuse fields; this is borne out by the results.

The degree to which the introduction of diffusers into a reverberation room alters the absorption coefficient of a material, presumably depends upon the directional properties of the material. The absorption coefficients of carpet samples are not usually altered by the introduction of additional diffusing elements. Thus, carpets are close to being omnidirectional in their absorption characteristics. The measured absorption coefficients of ceiling tiles are more dependent upon the number of diffusers installed in the reverberation room. Therefore, ceiling tiles are probably more directional than carpet tiles in their absorbing properties. Materials that are more directional than ceiling tiles, show[3] an even greater variation in their measured absorption coefficients with the number of diffusers installed.

The absorption coefficients, above 400 Hz, of the ceiling tiles measured in the new reverberation room, are higher than those measured in the old reverberation room, even when diffusers had been installed in both rooms. It is possible that this is because there was inadequate diffusion in the old reverberation room even when the diffusers had been installed.

3.3 Sample distribution measurements

In order to compare the effects on absorption coefficient measurements of subdividing the sample, with the effects of adding diffusing elements, the absorption coefficients of either A2 (low frequency), A3 (mid and high frequency) or D2 (very low frequency) modular absorbers were measured in the old reverberation room. The measurements were made with the sample (area 7.2 m^2) either laid out as one patch on the floor of the room, or as three patches on three walls and one patch on the floor. Each measurement was made either with no additional diffusing elements present, or with six acrylic diffusing sheets randomly suspended from the ceiling of the reverberation room.

It was shown in Section 3.1 that the sound field in the new reverberation room was sufficently diffuse to permit reliable ISO-Standard measurements above 80 Hz. The absorption coefficients of the A2, A3 and D2 absorbers were also measured in the new reverberation room (diffusers installed); the samples were measured either as one patch or in four patches.

The intention was to investigate the reproducibility[1]* of measurements between the old and new reverberation rooms, and to discover whether adding additional diffusing elements to the old reverberation room, or subdividing the sample, would achieve adequate diffusion (edge effects should be comparable in both reverberation rooms for the same sample disposition). The results of the measurements are shown in Figs. 9 - 14.

3.3.1 Measurements on A2 absorbers

When the A2 absorbers were measured as one patch, (ISO-Standard method) the results (shown in Fig. 9) were not very consistent between the new and old reverberation rooms (especially between 80 Hz and 125 Hz), even if the diffusers had been installed in the old reverberation room. The reverberation decays will be dominated by the modes at low frequencies. The absorbers will only interact with the modes for floor-to-ceiling reflections. Horizontal modes will be relatively unaffected by the absorbers. Therefore the measured absorption coefficients will be low at those frequencies where horizontal modes dominate. The acrylic diffusers are not very effective at low frequencies and will not have a significant effect on the dominance of the unabsorbed modes. In the new reverberation room, the modal density at low frequencies is sufficiently high for the effects of the modes on measurements to be averaged out.

When the A2 absorbers were arranged as four patches (BBC method), fairly consistent results (shown in Fig. 10) were obtained between the old and new reverberation rooms. Although the modal density at low frequencies in the old reverberation room is low, the absorbers will interact with all of the modes in a similar manner. Measurements were reliable whether or not diffusers had been installed in the old reverberation room. Note that the measurement made in the new reverberation room, using the BBC method, shows fairly close agreement with that made in the new reverberation room, using the ISO-Standard method.

The ISO-Standard method was originally developed from detailed studies of measurements made in a large number of reverberation rooms. The method results in a good reproducibility between ISO-Standard reverberation rooms because edge effects are minimised. Using the ISO-Standard method in the new reverberation room should give results which agree closely with those obtained in other ISO-Standard reverberation rooms, even though low frequency measurements will not agree with those made in the old reverberation room; the old reverberation room is too small to comply with ISO-Standard size requirements for such low frequencies.

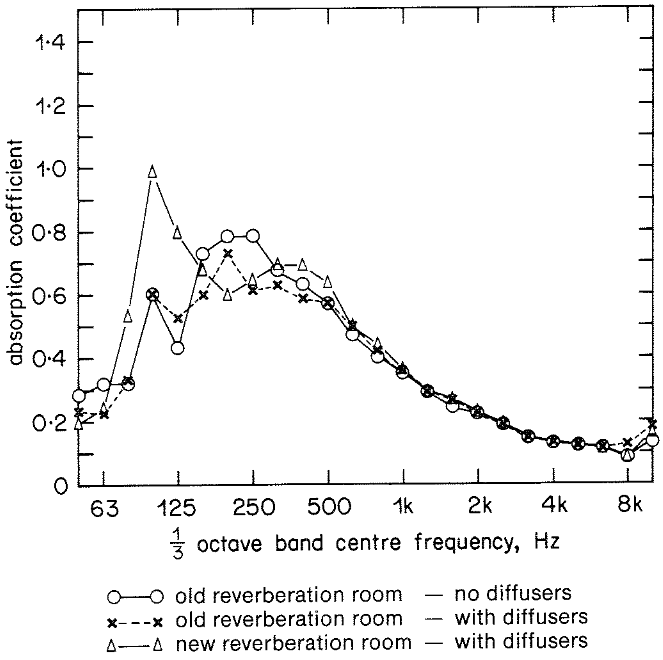


Fig. 9 - The effects of measurement environment on the absorption coefficients of a single patch of A2 modular absorbers.

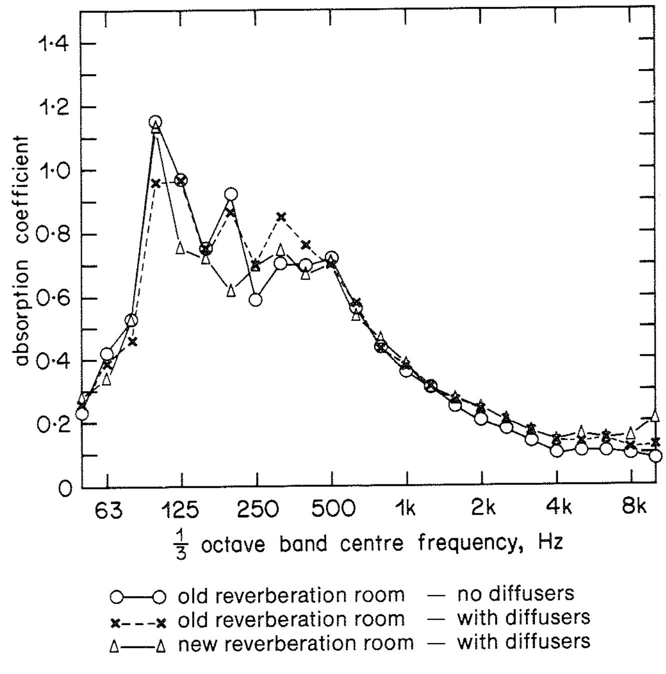


Fig. 10 - The effects of measurement environment on the absorption coefficients of four patches of A2 modular absorbers.

* Reproducibility is a term used in statistics, to describe the value below which the absolute difference between two single test results, obtained using the same method on identical test material, under different conditions, may be expected to lie within a probability of 95%.

3.3.2 Measurements on A3 absorbers

When the absorption coefficient of one patch of A3 absorbers in the old reverberation room was measured (Fig. 11), the results showed that there was insufficient diffusion without diffusers being installed, particularly above 500 Hz. Because the absorption coefficient measured in the old reverberation room, with diffusers installed, shows reasonable agreement with the measurement made in the new reverberation room, the state of diffusion in the old reverberation room is adequate over the frequency range in which the A3 absorbers predominantly absorb.

For the measurements on four patches of A3 absorbers (Fig. 12), the results show that there was

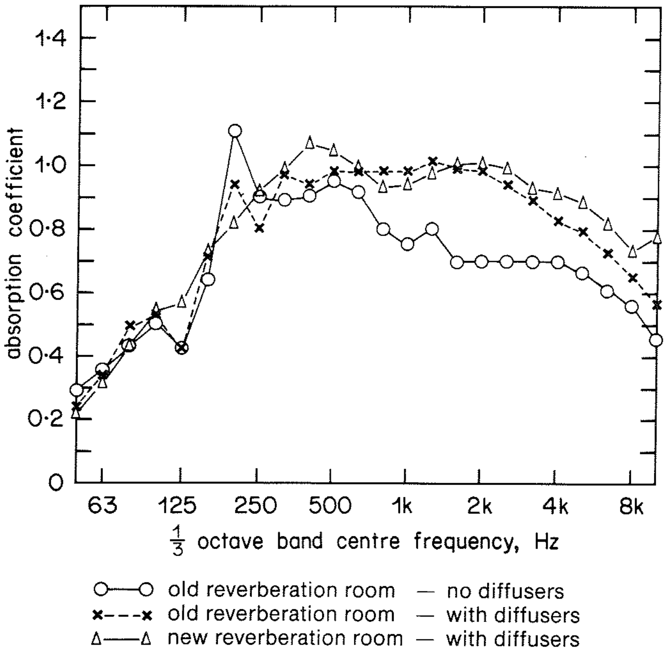


Fig. 11 - The effects of measurement environment on the absorption coefficients of a single patch of A3 modular absorbers.

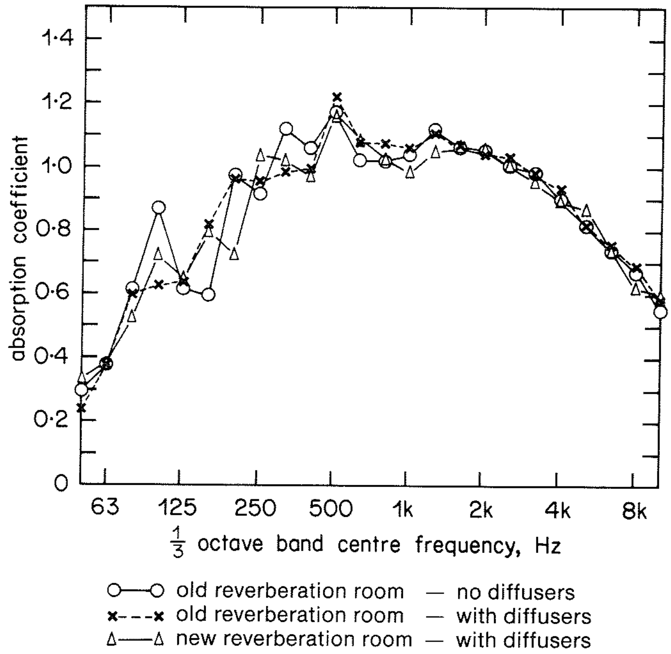


Fig. 12 - The effects of measurement environment on the absorption coefficients of four patches of A3 modular absorbers.

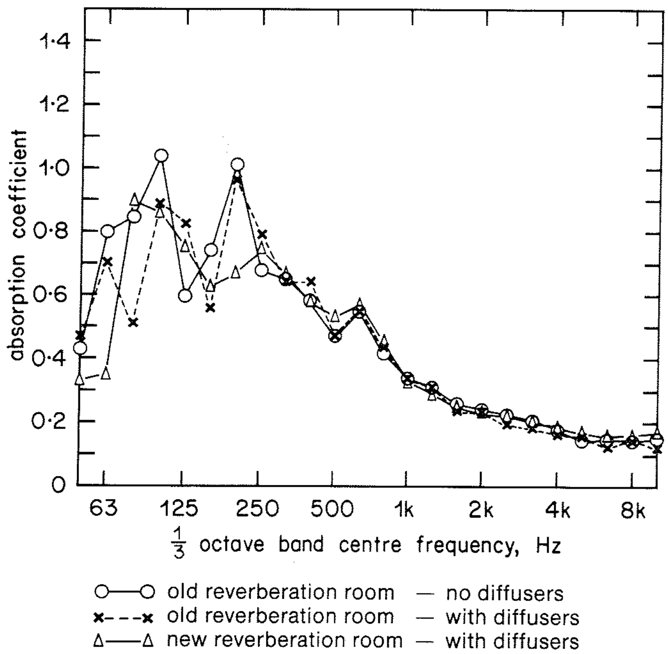


Fig. 13 - The effects of measurement environment on the absorption coefficients of a single patch of D2 modular absorbers.

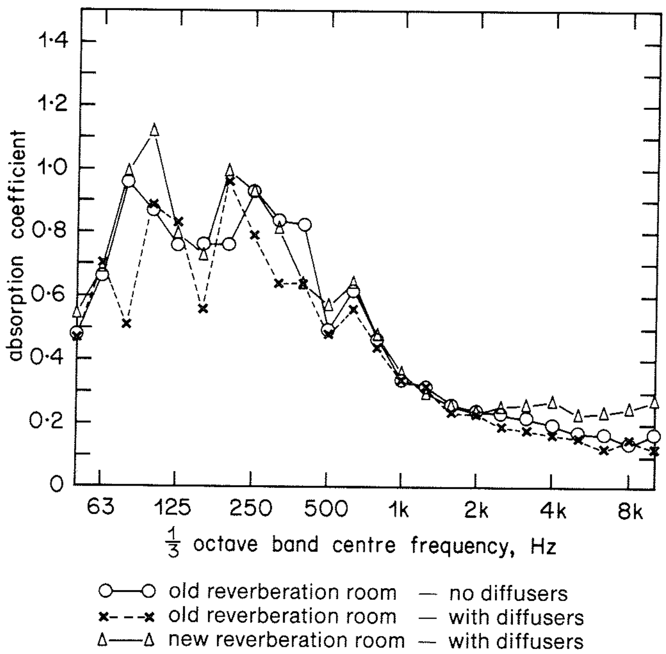


Fig. 14 - The effects of measurement environment on the absorption coefficients of four patches of D2 modular absorbers.

sufficient diffusion to ensure reliable measurements, whether or not diffusers were installed in the old reverberation room. Measurements in the old and new reverberation rooms showed closer agreement when using the BBC method of measurement rather than the ISO-Standard method.

3.3.3 Measurements on D2 absorbers

The results of absorption coefficient measurements on D2 modular absorbers (Figs. 13 and 14) are inconclusive because the working frequency range of the D2 absorbers is so low that measurements made in the old reverberation room would not be reliable. Subdivision of the sample and the introduction of additional diffusing elements do not seem to make measurements more reproducible.

3.3.4 Comments

Although the ISO-Standard method has been shown by others outside the BBC to give results which are very reproducible in many other ISO-Standard reverberation rooms, it does not give good results when used in the old reverberation room, due to its small size. The acrylic diffusers do not perform sufficiently well at low frequencies to overcome the strong influence of the room modes on the measured absorption coefficients. However, the effects of individual room modes on the absorption coefficients measured in the old reverberation room can be reduced by subdividing the sample (using the BBC method); additional diffusing elements are not then required. For measurements in the new reverberation room, the differences between the measurements for each method are not large and either method would achieve an adequate repeatability[1]*.

4. EDGE EFFECTS

4.1 Sample subdivision

Subdividing a sample in a reverberation room usually increases the measured absorption coefficient of a sample. The increase in measured absorption is generally linked with the increased edge length of the sample; this is provided that the sound field is sufficiently diffuse that subdividing the sample has only a small effect on the state of diffusion in the room. Another possible explanation for the increase in effective absorption is that some interaction occurs between the various patches of absorber which were distributed on the different room surfaces.

To determine the cause of the increase in absorption that occurs on the subdivision of the sample, the absorption coefficient of a single patch of A3 modular absorbers, of area 1.8 m^2, was measured. In Fig. 15, this absorption coefficient is compared with that of 7.2 m^2 of A3 absorbers subdivided into four patches, each of similar area, on four room surfaces. The absorption coefficient of a single patch of A3 absorbers, of area 7.2 m^2, is also shown for reference. Experimental errors will be larger when the sample area was 1.8 m^2 because the difference between the treated and untreated room reverberation times were smaller. High absorption coefficients (corresponding to greater differences between treated and untreated room reverberation times) will be more accurate than lower absorption coefficients.

The absorption coefficients for the single small patch agree well with those for the four patches between 400 Hz and 5 kHz. The differences below 400 Hz could be a result of experimental errors. These could be caused by the small sample area, or result from some difference in the interaction of the absorber with modes in the room, when using the single patch rather than four patches (as a result of the positions of the patches in the room). The differences above 5 kHz could be caused either by experimental errors, resulting from the small sample area, or possibly an incorrect evaluation of air absorption values.

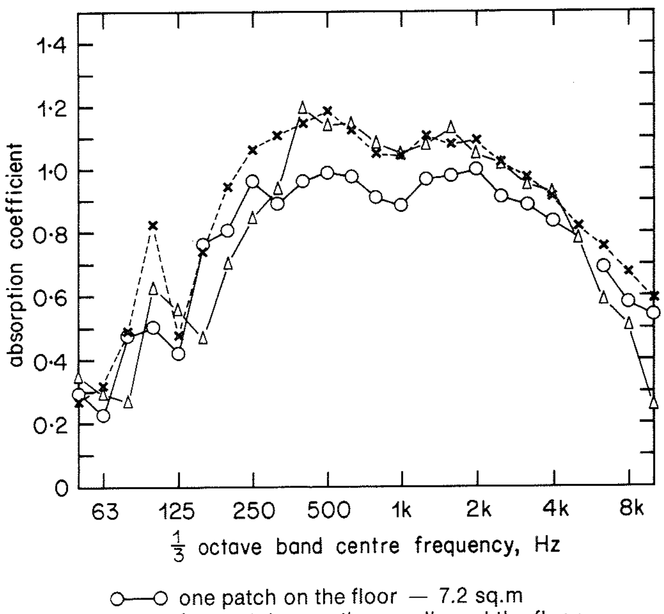


Fig. 15 - The effects of sample area and distribution on the absorption coefficients of A3 modular absorbers measured in the old reverberation room.

* Repeatability is a term used in statistics, to describe the value below which the absolute difference between two single test results, obtained using the same method on identical test material, under the same conditions, may be expected to lie within a probability of 95%.

These results show that the absorption coefficient of a single, small patch of the absorbers is effectively the same as the absorption coefficient of four similar-sized patches. This proves that patches of absorbers of the same type do not interact in a sparsely treated room. Therefore, the increase in effective absorption on subdividing a sample is not linked with some interaction between the different patches of the subdivided sample.

Presumably, the measured absorption coefficient of the ISO-Standard recommended area (10 - 12 m^2) of a material would be similar to that of four patches of the same material — each patch being of the ISO-Standard recommended area — mounted on four room surfaces. This hypothesis should apply, provided that the room is still relatively untreated, so that edge effects still predominate. It was intended to verify this hypothesis but sufficient absorbers were not available.

4.2 Sample area

It is important to select an appropriate sample area when making absorption coefficient measurements in reverberation rooms. If the sample area is too small, edge effects will be significant and the uncertainty in results may be too high; consequently, the change in reverberation time on treating the reverberation room with a small sample may be insufficient. If the sample area is too large, the surrounding walls will influence the measured absorption coefficient. The ISO-Standard method for the measurement of the absorption coefficients of materials in reverberation rooms recommends a sample area of 10 - 12 m^2, and a reverberation room volume of at least 200 m^3.

It is useful to know the extent to which the measured absorption coefficient is affected by the sample area; so that, for example, if less than 10 m^2 of sample is available, an estimate can be made of the resultant increase in the effective absorption coefficient that would be expected. Studies of the effects of the sample area on the measured absorption coefficients should also provide further information on the effective absorption coefficients of materials in lightly or heavily treated rooms.

4.2.1 Mineral wool

The absorption coefficients of different areas of 50 mm thick mineral wool batts were measured in the new reverberation room. The sample was measured as one patch with a ratio of length to width of between 0.7 and 1.0. For the largest sample area, the floor of the room was 75% covered. Twelve acrylic diffusing sheets were suspended in the room. The results are shown in Fig. 16 and Fig. 17.

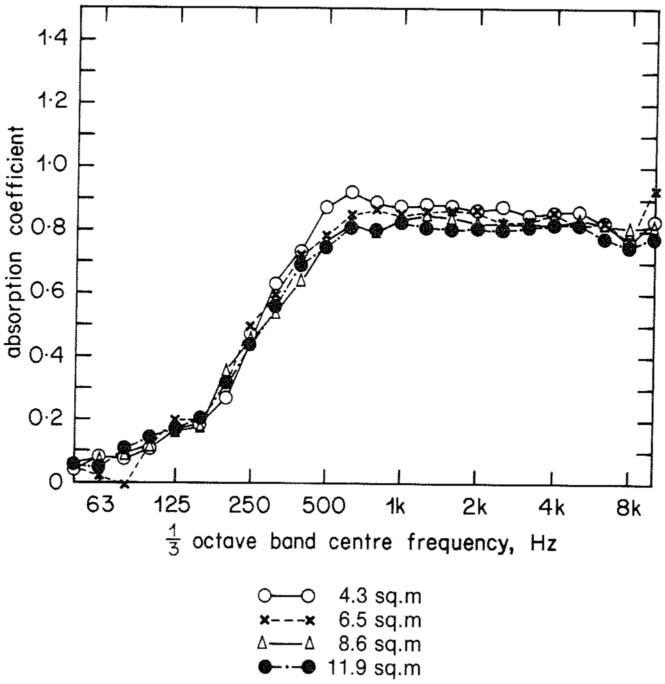


Fig. 16 - The effects of the sample area of 50 mm thick mineral wool batts on their measured absorption coefficients.

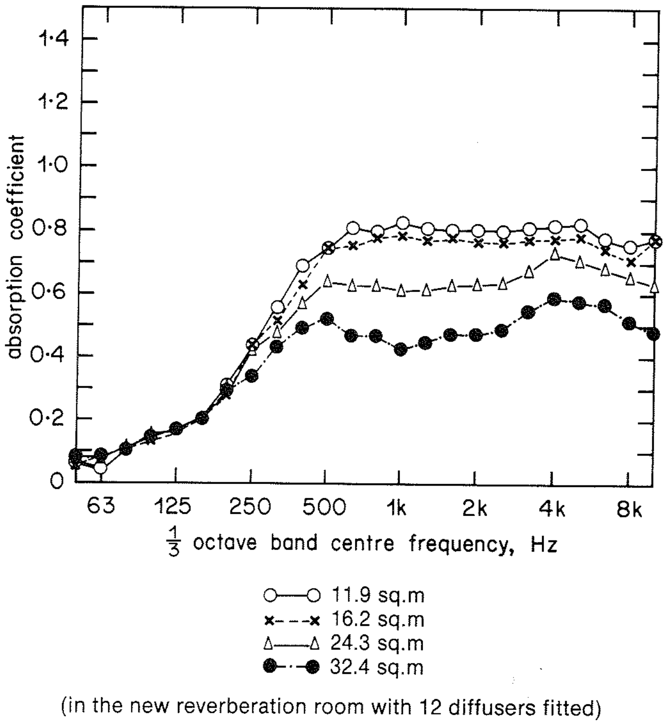


Fig. 17 - The effects of the sample area of 50 mm thick mineral wool batts on their measured absorption coefficients.

There are no significant differences between the curves below 200 Hz where the mineral wool has a relatively low absorption coefficient. Above 200 Hz, the measured absorption coefficients decrease as the ratio of edge length to sample area reduces. The absorption coefficient measurements are only slightly

affected by sample areas of up to 16.2 m^2. For sample areas of 24.3 m^2 and 32.4 m^2, the absorption coefficients are much lower than those measured with smaller sample areas. This observation is similar to that made elsewhere[7] for measurements on a comparable sample. The relationship between the absorption coefficient of a material, and the ratio of the exposed edge length to surface area of an absorber, is linear for large samples. For smaller samples, the linear relationship no longer applies; the absorption coefficient tends to a limiting value. This occurs when the sample becomes sufficiently small, so that different edges cannot be assumed to be independent of each other.

An important conclusion from these measurements, is that any small changes in sample area around the ISO-Standard recommended area, will have only a small effect on the measured absorption coefficient of a material. Also, when the floor is 75% treated, the total absorption at higher frequencies is only slightly greater than when the floor is 37.5% treated. So there is a potential saving in acoustic treatment costs in rooms where heavy acoustic treatment would usually be employed. It is probable that for a fully treated wall, removing half of the treatment would only have a slight effect on the overall absorption. In fact, if the remaining absorbers were arranged in a chequerboard pattern, the reduction in absorption caused by removing half the absorbers may be minimal. The chequerboard pattern would also improve the state of diffusion in the room.

It must be stressed, that the effect of the overall absorption, of a 37.5% treated room surface being comparable with the overall absorption of a 75% treated room surface, has *only* been observed for a single material (mineral wool) on the floor of a reverberation room. There is *no guarantee* that similar savings in acoustic treatment could be made for all types of absorber, or that the same result would apply if the other room surfaces were acoustically treated, as in a studio. Also, the percentage change in measured absorption, with sample areas of large dimensions, may be less for a material with a lower absorption coefficient.

4.2.2 Modular absorbers

Samples of prototype modular absorbers[14] were used to study the effects of sample area on measured absorption coefficients at low frequencies. Measurements of the absorption coefficients of different areas of the modular absorbers were made in the new reverberation room with twelve acrylic diffusing sheets installed. The results are shown in Fig. 18.

Significant differences between the curves only

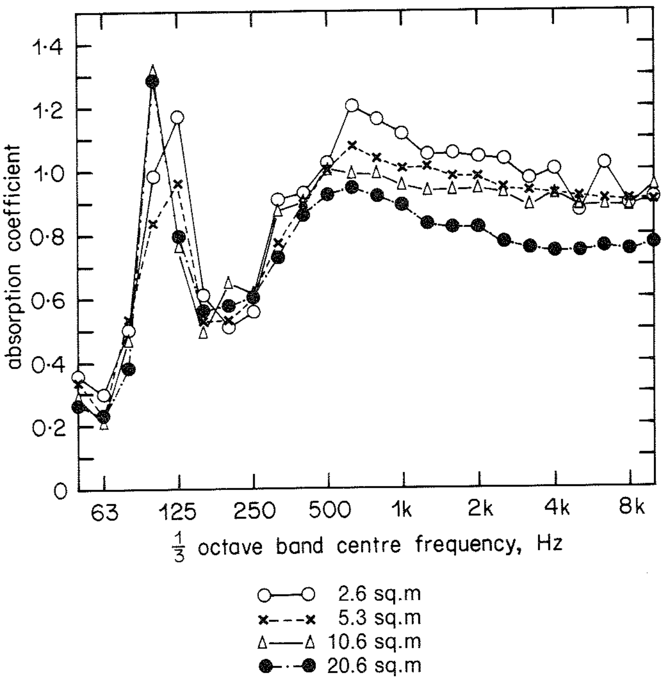


Fig. 18 - The effects of the sample area of prototype modular absorbers on their measured absorption coefficients.

occur when the absorption coefficients are above a value of 0.7. The absorption coefficient curves change shape as the sample area is increased. Above 250 Hz, the measured absorption coefficients reduce as the sample area increases. The curves for areas of 5.3 m^2 and 10.6 m^2 show the closest agreement of any pair to each other.

Below 160 Hz, the trend in the variation of measured absorption coefficient with sample area is more erratic than at higher frequencies (the progression is not uniform, as the curve for a sample area of 2.6 m^2 is between that for 5.3 m^2 and 10.6 m^2). The low frequency peak in the measured absorption coefficient curve, seems to shift to a lower frequency as the sample area is increased; the peak value of absorption coefficient increases to reach a constant value at a sample area of 10.8 m^2. These curves show that a sample area of approximately 11 m^2 will give absorption coefficient measurements which are least affected by sample area, at both low and high frequencies. The ISO-Standard, for absorption coefficient measurements in a reverberation room, recommends a sample area between 10 and 12 m^2 for a room with the size of the new reverberation room.

5. CONCLUSIONS

The current BBC method for the measurement of the absorption coefficient of materials in a reverberation room, differs from the ISO-Standard

method in the use of additional diffusion in the room and in the distribution of the sample. In the ISO-Standard method, adequate diffusion is achieved by the use of additional diffusing elements, whereas the BBC method relies on the distribution of the sample.

Furthermore, in the ISO-Standard method, the sample is laid out on the floor of the reverberation room as one patch of rectangular shape. In the BBC method, materials that are usually mounted as one patch on one surface of a room, are measured as one patch on the floor of the reverberation room. With materials that are usually distributed over several room surfaces, the material is measured as four patches of approximately equal area and these patches would be mounted on three walls and the floor of the reverberation room.

A requirement of the measurement method used is that it should give results which are reasonable approximations to the effective absorption coefficients of materials in any room. The measurement method should also give results which are both repeatable and reproducible[1].

In an experimental sound control room, the measured absorption coefficients of absorbers, were generally lower than the measurements made in the reverberation room. There were much smaller differences between the measurements made using the two reverberation room methods, than there were between the effective absorption coefficients measured in the sound control room and *either* of the reverberation room measurements.

Measurements showed that ISO-Standard absorption coefficient measurements are more suitable when designing heavily treated rooms. Absorption coefficient measurements made using the BBC method are more appropriate to the design of sparsely treated rooms.

The ISO-Standard method has been shown by others, outside the BBC, to give results which are very reproducible in many other ISO-Standard reverberation rooms. However, the method does not give good results when used in the old reverberation room, because of the room's small size. Installing additional diffusing elements in the room does not overcome these difficulties. Subdividing the sample in the old reverberation room (using the BBC method) significantly reduces the effects of the inadequate modal density in the room. Additional diffusing elements are not then required.

Subdividing a sample increases the effective absorption of a single material. The increase in absorption can be linked with the increase in the exposed edge length of the absorber. The measured absorption coefficient decreases as the ratio of edge length to sample area reduces. The variability in absorption coefficient measurements caused by edge effects is minimised by using the ISO-Standard method. Small changes in sample area, around the ISO-Standard recommended area, have only a small effect on the measured absorption coefficient of a material. Using the ISO-Standard recommended sample area, produces absorption coefficient measurements which are least affected by sample area at all frequencies. However, the differences between the measurements for each method are not large and either method would achieve adequate repeatability in the new reverberation room.

6. RECOMMENDATIONS

For measurements in the old reverberation room, the existing BBC method for the measurement of the absorption coefficients of subdivided samples should be used; additional diffusing elements are not then required. If the sample cannot, or would not usually be subdivided, additional diffusing elements must be installed in the room.

Recent changes include: the construction of a new ISO-Standard reverberation room at Research Department; the widespread use of the ISO-Standard by other laboratories; and the shift to more heavily treated rooms in the BBC. These are significant enough changes to justify the use of the ISO-Standard method to measure the absorption coefficients of materials in the new reverberation room. The use of the ISO-Standard method should reduce the influence of edge effects on measured absorption coefficients. Samples of materials for measurement in the new reverberation room should only be subdivided when the results are to be used for the design of large, sparsely treated rooms. If a subdivided sample method is used, the results should be clearly labelled as not conforming to the ISO-Standard for measurement.

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APPENDIX

Details of the Old and New Reverberation Rooms

The floor plan of the old reverberation room is shown in Fig. A1 (dimensions are in metres). As can be seen, the room is non-rectangular — the corners are angled differently. All the walls are vertical and both the floor and the ceiling are horizontal. The floor to ceiling height is 3.03 m. All room surfaces are finished with glazed tiles.

The new reverberation room is rectangular. The floor is 5.90 m by 7.40 m and the room height is 4.62 m. The floor is a reinforced concrete slab with a granolithic finish. The ceiling is made from precast concrete slabs. The walls are brick and are finished with a painted sand-cement render.

Fig. A1 - Floor plan of the old reverberation room.